J. Bangladesh Electron. 12 (1-2); 75-80, 2012

Improvement of Positioning Accuracy of WAAS

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Abstract

Satellite based augmentation system (SBAS) is a more accurate method of navigation than the GPS especially in case of precision approach. In various region of the world SBAS system is at the phase of implementation. It is must be mention that both WAAS and GPS or in other worlds satellite navigation is not liberated from error. In this paper the details of ionosphere and troposphere error, which are the most affective causes of error, have been discussed. Among GPS and WAAS the influence of ionosphere and troposphere is more on the earliest one. To overcome the ionosphere error of GPS, WAAS is a better method of navigation. But For future navigation method dual frequency ranging will play a vital role for standalone navigation as the ionosphere delay can be calculated by the user himself by using dual frequency. A brief discussion about L1, L2 and L5 frequency has been highlighted. It may be mentioned that the combination of any of these two frequencies makes dual frequency. In this paper it is also shown that how L1/L5 dual frequency is better than the other options.

Keywords - WAAS, SBAS, Dual frequency and L1/L2/L5.

1. INTRODUCTION

GPS is one of the current most advanced positioning systems. Although in some extant it cannot meet the necessity of exact positioning e.g. the precision approach of aircraft in civil aviation. So some augmentation measures are necessary for fulfilling the requirement of accuracy, integrity, continuity and availability; which are the properties that a navigation method should posses. Based upon this, Federal Aviation Administration (FAA) has developed a Satellite Based Augmentation system (SBAS) named WAAS [1], which is operational for aviation since 2003 in the region of America. EGNOS in Europe, MSAS in Japan is implemented and GAGAN is soon to be developed in India.

WAAS provides correction to GPS through a network of 38 reference stations at precisely known locations throughout the U.S. These reference stations receivers, which are called WAAS reference stations (WRSs), continuously, monitor all of the GPS satellites and their propagation environment in real time. The WAAS provides Signal in Space (SIS) to all aircraft with approved avionics using the system for any approved phases of flight. The broadcast SIS provides two functions: (1) messaging (data on GPS and Geostationary Earth Orbit satellites) and (2) a ranging capability. These data are forwarded to Wide Area Master Stations (WMSs), which process the information to determine differential satellite corrections, GEO orbital parameters, ionosphere and troposphere corrections. In total these functions are called Correction and Verification (C&V). The WAAS-generated information is sent from the WAAS Master Station (WMSs) to the GEO Uplink Subsystem (GUS) and uplinked to GEO satellites. The GEO satellites broadcast the WAAS SIS to the users with GPS type modulation.

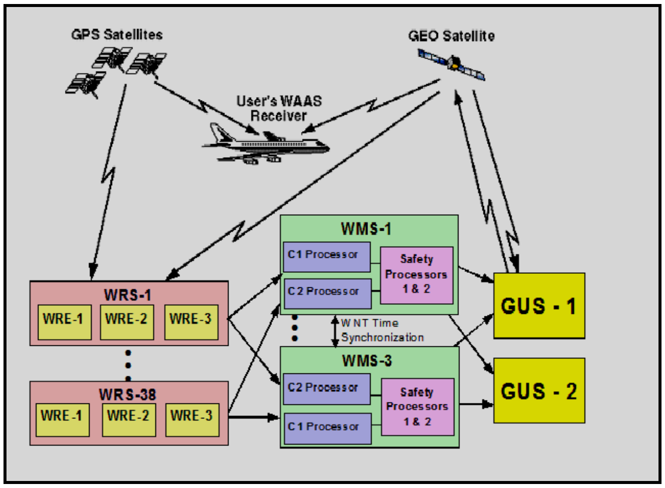

Fig 1: WAAS Architecture.

2. CORRECTION AND VERRIFICATION

The ionosphere is the largest error source for GPS and WAAS. These signals are refracted by free electrons in the ionosphere, which extends from 50 to 1000 km above the earth's surface and gas in troposphere which extents about 12 Km about the earth surface. Signals from low elevation satellite experiences much more refraction than the high elevation satellite [2]. The propagation of ionosphere function can be given as

$$\delta\rho_{ij} = \left[1 - \left(\frac{R\cos\theta_{nu,j}}{R + h_i}\right)^2\right]^{\frac{1}{2}} \qquad (1)$$

A minimum elevation threshold, known as the mask angle, of between 5° and 10°, is required for navigation solution [2]. Satellites signals below the mask angle are excluded from the navigation solution. Similarly the troposphere propagation delay varies approximately as

$$\delta\rho_{tj} = \left[1 - \left(\frac{\cos\theta_{nu,j}}{1.001}\right)^2\right]^{-\frac{1}{2}} \qquad (2)$$

The Ionosphere and troposphere delay mapping function using MATLAB simulation is shown as below in Fig 2.

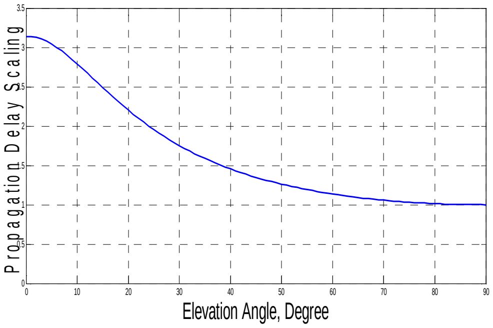

Fig 2a: Ionoshere delay mapping.

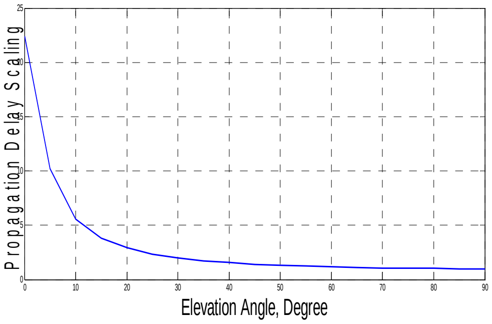

Fig 2b: Troposphere delay mapping.

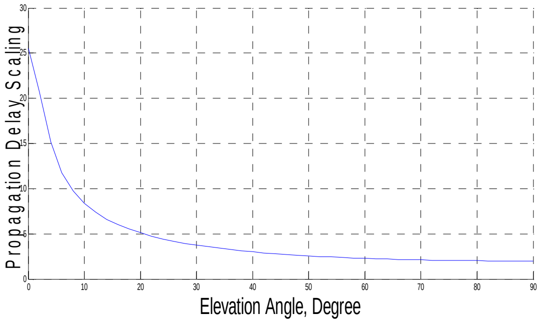

Fig 2c: Total delay for ionosphere and troposhere.

Fig 2a and Fig 2b shows that with the increase of elevation angle the accuracy related to ionosphere and troposphere respectively increases or in other terms the error reduces. Fig 2c represents the total delay caused by the ionosphere and troposphere.

Ionospheric scintillation due to electron density irregularities in the ionosphere can cause deep irregularities and frequent transionospheric signal fading. The carrier to noise density ratio (C/N_0) of a received GPS/WAAS signal remains nearly constant over 100s when scintillation is not present [3]. However, if strong scintillation is present C/N_0 fluctuates rapidly and fades of more than 25 dB can occur.

The future WAAS message could include new message bits to indicate the presence of ionosphere strome, in addition to the grid ionosphere vertical error (GIVE) [3] messege. This particular WAAS message would be received by the aircraft. If there are cycle slips and if the aircraft has such ionosphere storm detector information available (showing no ionosphere storm), then that aircraft can use the WAAS ionosphere threat model technique to bound the ionosphere error while it is descending. If there is an ionosphere storm but no available ionosphere storm detector, an aircraft has to use maximum ionosphere delay gradient model.

$$\sigma_{MAX\ IONO\ Gradient} = \begin{cases} \left(\frac{6m}{5.33}\right)\left(\frac{d}{19}\right)T & if\ 0 < d < 19 \\ \left(\frac{6m}{5.33}\right).T & if\ d > 19 \end{cases} \qquad (3)$$

Where d is the distance from the current position to the place with the last dual frequency ionosphere delay estimation, and T is the multiplier to translate the static receiver model to dynamic receiver model. It is called as follows

$$T = \frac{V_{Iono_{wall}} + V_{IPP} + V_{aircraft}}{V_{Iono_{wall}}} \qquad (4)$$

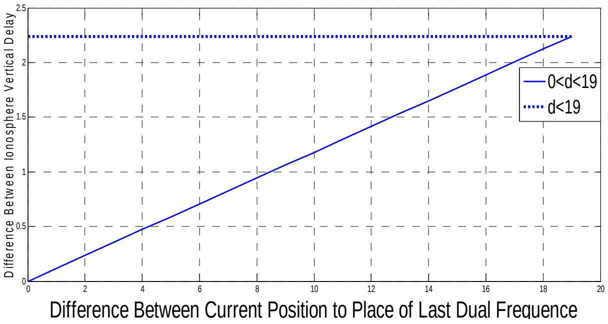

Fig 3: Maximum delay gradient.

Using MATLAB simulation for Eq. 3 which is shown in Fig 3, the measured ionospheric vertical delay from location 0 to 19 Km could be ≈ 2.25 m. It can provide the user whether to use the WAAS positioning or look for the supplementary system.

By using modernized L1-L5 dual frequency user can estimate ionospheric delay directly and subtract this estimation from pesudorange. Utilization of modernized GPS signal is expected to enhance this performance.

3. L1, L5 AND DUAL FREQUENCY

GPS uses L1 (1575.42 MHz) and L2 (1227.6 MHz) frequency band. Between these two only L1 has a code C/A (civil code) fully accessible for the civil user. Modernized GPS will have L5 (1176.45 MHz) frequency which is called Safety of Life Code (SoL) and all three frequency will have civil codes. For modernized GPS since L1 and L5 are available for civil aviation safety-of-life services, the WMS is able to use these signals to generate corrections for both frequencies. As a result the nominal WAAS airborne user is also an L1-L5 dual-frequency user. The dual frequency is the combination of two frequencies L1-L5. Today satellite based augmentation system (SBAS) utilizes dual frequency L1-CA/L2 semi codeless measurement to provide precise correction and integrity bound to aircraft for both enroute and precision approach operations. Moreover Aeronautical Radio Navigation Service (ARNS) frequency band is opening the door to development of dual frequency L1/L5. Subsequently in this paper we will show that the dual frequency provides a better accuracy than the single frequency.

By using dual frequency version satellite based augmentation system will improve the performance of the entire positioning system. Far better advantage of L1/L5 GEO satellite ranging capabilities, operate without the loss of availability during solar storm and provide better continuity and availability, also in equatorial region, where ionospheric disturbance are observed on regular basis, dual frequency can bring a impressive change [2]. In this regard it may be mentioned that twenty four L5 capable satellites will be fully operational by the year of 2018. To provide seamless cutover from a single frequency system to dual frequency system, the FAA is considering replacing the existing dual frequency L1/L2 semi codeless receivers in the WAAS ground system with receivers capable of processing L1, L2 and L5 signals.

In case of dual frequency satellite, the measurement of noise terms is increased to account for the noise from of both L1 and L5 frequency [1]. For single frequency satellite we find:

$$\sigma_{multipath} = 0.13 + 0.53e^{(-\frac{\theta}{1}} \qquad (5)$$

GPS: $$\sigma_{noise} = 0.15 - \frac{\theta - 10^\circ}{80} * (0.15 - 0.1 \qquad (6)$$

GEO: $$\sigma_{noise} = 1.8 - \frac{\theta \quad 10^\circ}{80} * (1.8 - 1. \qquad (7)$$

For dual frequency satellite we multiply the single frequency values for $\sqrt{(\sigma_{noise}^2 + \sigma_{multipath}^2}$ by

$$\sqrt{\left(\frac{f_1^2}{f_1^2 - f_5^2}\right)^2 + \left(\frac{f_5^2}{f_1^2 + f_5^2}\right)^2} \qquad (8)$$

Where $f_1 = 1575.42E6 \; and \; f_5 = 1176.45$

Now using MATLAB simulation result for single frequecy GPS and single frequency GEO has been shown in Fig 4.

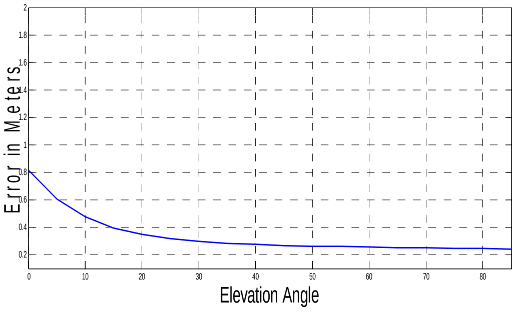

Fig 4a: Error for single frequency GPS

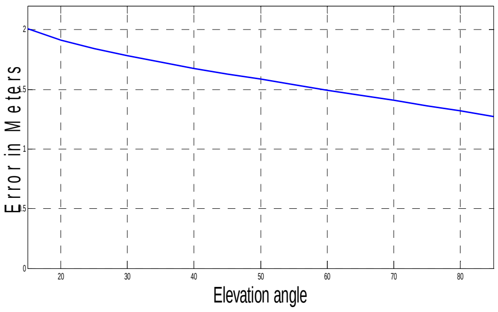

Fig 4b: Error for single frequency geo

For dual frequency satellite comparing it with the single frequency satellite, a clear difference is found. The simulation using MATLAB is as below:

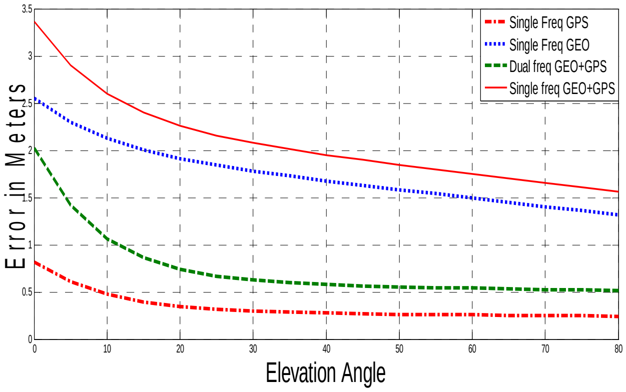

Fig 4c: Comparission between single frequency and dual frequency GEO and GPS signal.

From Fig 4c it is found that the accuracy for dual frequency GPS and GEO is much more than the single frequency GEO and GPS. From the simulation it can also be mentioned that the error in dual frequency GPS and GEO signal is even less than the single frequency GEO alone. Moreover from Fig 4a, Fig 4b and Fig 4c it is found that the amount of accuracy is increased with the increase of elevation angle, as with the increase of elevation angle the amount of in view satellite is increasing.

As mentioned earlier Aeronautical Radio Navigation Service (ARNS) frequency band is opening the door to development of dual frequency L1/L5. Using MATLAB simulation we can find out reason of using L1/L5 frequency for dual mode frequency instead of L1/L2 or L2/L5.

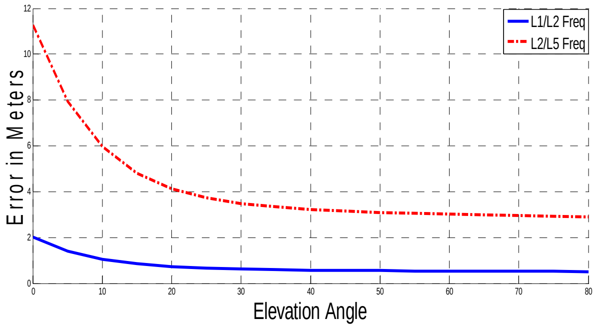

Fig 5a: Comparison between L1/L2 dual frequency and L2/L5 dual frequency.

From Fig 5a it is found that L1/L2 dual frequency is lot better than L2/L5 dual frequency in terms of accuracy. Again if we compare the error between L2/L5 and L1/L5 then we find the result in Fig 5b.

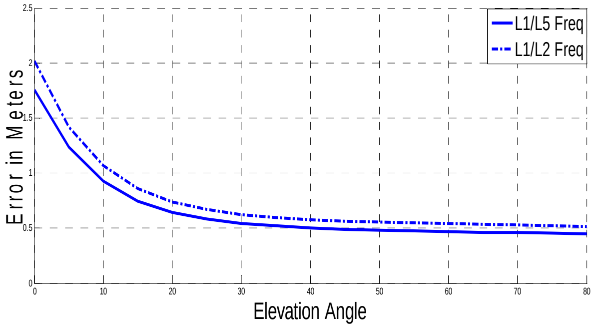

Fig 5b: Comparison between L1/L2 dual frequency and L1/L5 dual frequency.

From Fig 5b we find that L1 and L5 frequency is even better than L1/L2. The amount of error is reduced. So use of L1/L5 frequency is the best solution for dual frequency ranging. The GEO satellite always has a larger value for σ_{noise} because of the possibility that the satellite has a narrow bandwidth which introduces errors when mixing the range measurement with GPS satellite as found in Fig 4b and Fig 4c.

4. CONCLUSSION

Simulation result reveals that use of modernized L5 SoL frequency reduces error and enhances the performance of GPS and WAAS navigation system. The use of dual frequency reduces the error rather than using single frequency. The execution of dual frequency by the year of 2018, through L1 and L5 frequency band, will reduce the amount of error. It can also be said that L1/L5 frequency is the best combination for dual frequency ranging than any other combination.

The further direction of these studies can guide to an even better frequency than L1/L5 dual frequency of the GPS signals to reduce the amount of error in positioning.

REFERENCES

[1] Tim Schempp, Stephen Peck. “Incremental Benefits of Dual Frequency Signals for the Wide Area Augmentation System” *Proceedings of IEEE/ION PLANS 2010, Page 645 – 653*, *May 4 - 6, 2010.*

[2] Principles of GNSS, Inertial and Multisensor Integrated Navigation System. Paul D. Groves.

[3] Enge P. Walter, T. Pullen. “Wide Area Augmentation of Global Positioning System” *Proceedings of IEEE, 84*.

[4] Euiho Kim, Uri Peled, Todd Walter. “A Development of WAAS Aided Flight Inspection Truth System” *Proceedings of IEEE/ION PLANS 2006, Page 61 – 70, 2006.*